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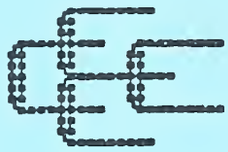

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National Bureau of Standards
Gaithersburg, Maryland 20899

Technical Progress Bulletin

Covering Center Programs, July to September 1987, with 1988 CEEE Events Calendar

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INTRODUCTION TO FEBRUARY 1988 ISSUE OF THE CEEE TECHNICAL PROGRESS BULLETIN

This is the twentieth issue of a quarterly publication providing information on the technical work of the National Bureau of Standards Center for Electronics and Electrical Engineering. This issue of the CEEE Technical Progress Bulletin covers the third quarter of calendar year 1987.

Organization of Bulletin: This issue contains abstracts for all Center papers released for publication by NBS in the quarter and citations and abstracts for Center papers published in the quarter. Entries are arranged by technical topic as identified in the table of contents and alphabetically by first author under each subheading within each topic. Unpublished papers appear under the subheading "Released for Publication". Papers published in the quarter appear under the subheading "Recently Published". Following each abstract is the name and telephone number of the individual to contact for more information on the topic (usually the first author). This issue also includes a calendar of Center conferences and workshops planned for calendar year 1988 and a list of sponsors of the work.

Center for Electronics and Electrical Engineering: Center programs provide national reference standards, measurement methods, supporting theory and data, and traceability to national standards.

The metrological products of these programs aid economic growth by promoting equity and efficiency in the marketplace, by removing metrological barriers to improved productivity and innovation, by increasing U. S. competitiveness in international markets through facilitation of compliance with international agreements, and by providing technical bases for the development of voluntary standards for domestic and international trade. These metrological products also aid in the development of rational regulatory policy and promote efficient functioning of technical programs of the Government.

The work of the Center is divided into two major programs: the Semiconductor Technology Program, carried out by the Semiconductor Electronics Division in Gaithersburg, MD, and the Signals and Systems Metrology Program, carried out by the Electrosystems Division in Gaithersburg and the Electromagnetic Fields and Electromagnetic Technology Divisions in Boulder, CO. Key contacts in the Center are given on the back cover; readers are encouraged to contact any of these individuals for further information. To request a subscription or for more information on the Bulletin, write to CEEE Technical Progress Bulletin, National Bureau of Standards, Metrology Building, Room B-358, Gaithersburg, MD 20899 or call (301) 975-2220.

Center sponsors: The Center Programs are sponsored by the National Bureau of Standards and a number of other organizations, in both the Federal and private sectors; these are identified on page 33.

Note on Publication Lists: Guides to earlier as well as recent work are the publication lists covering the work of each division. These lists are revised and reissued on an approximately annual basis and are available from the originating division. The current set is identified in the Additional Information section, page 31.

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SEMICONDUCTOR TECHNOLOGY

Silicon Materials

Released for Publication

Thurber, W.R., and Lowney, J.R., **Methods for Accurate Determination of Emission Rate and Trap Concentration with Application to Platinum-Doped Silicon**, Journal of Applied Physics, Vol. 62, No. 2, pp. 534-540 (July 15, 1987).

A detailed analysis of junction capacitance was developed which allows one to extract accurate values of emission rate and trap concentration from isothermal transient capacitance measurements. Experiments were performed on silicon diodes doped with platinum. The capacitance-ratio method of determining the emission rate was used to remove the nonexponentiality due to large trap concentration from the capacitance transients. Arrhenius plots of scaled emission rate gave E_A = 0.2271 ± 0.0002 eV for the platinum acceptor level in n-type silicon, and E_A = 0.3215 ± 0.0012 eV for the platinum donor level in p-type silicon. A new method for determining the trap concentration is derived and verified by use of simulations and data. This method involves the subtraction of capacitance values obtained from two transients with the same fill voltage, but different reverse voltages. It is much simpler than methods which require iterative solutions of Poisson's equation and a priori knowledge of the trap energy.
[Contact: W. Robert Thurber, (301) 975-2067]

Analysis Techniques

Released for Publication

Robertson, P.J., Dumin, D.J., Carver, G.P., and Novotny, D.B., **Methodology to Determine the Crystal Quality of Thin Silicon Films Using MOS Device Parameters.**

A methodology is presented which was used to examine the quality of a silicon epitaxial layer based on its suitability for use as a substrate for MOS devices. Transistor and capacitor measurements were used to derive the MOS characteristics of mobility, threshold voltage, surface state density, effective generation lifetime, and doping concentration. Basic material parameters may be inferred from these data. This methodology was used to characterize a silicon-on-boron phosphide process having 0.2- and 0.4-μm BP films covered by 1- to 5-μm silicon epitaxial layer on which enhancement-mode PMOS devices were fabricated. Impurity concentrations on 1- and 2-μm silicon layers were as high as 3×10^{17} cm^{-3} due to auto doping from the BP layer. MOS transistors manufactured on these layers did not work properly. Device characteristics improved on thicker silicon layers. The impurity concentration was as low as 10^{15} cm^{-3} on the 5-μm silicon layers. Surface state densities were found to be as low as 5×10^{11} states/cm^2 with subthreshold currents as low as 10^{-11} amperes. On all wafers, the subthreshold slope varied from 90 to 100 mV/dec with little variation due to silicon thickness. It was shown that silicon layers thicker than 3 μm were necessary to fabricate working devices due to high background doping concentrations. Characteristics of devices fabricated on 5-μm silicon layers were comparable to those of devices fabricated on bulk silicon processed at the same time indicating high-quality silicon growth.
[Contact: Gary P. Carver, (301) 975-2091]

Dimensional Metrology

Recently Published

Larrabee, R.D., **Submicrometer Optical Linewidth Metrology**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Vol. 775, Integrated Circuit Metrology, Inspection, and Process Control, pp. 46-50 (1987).

Dimensional Metrology (cont'd.)

[Conference, Santa Clara, California, March 1-6, 1987].

The National Bureau of Standards (NBS) has had a continuing program to develop optical linewidth standards for the integrated circuit industry for over 10 years. The past work has concentrated on the development and the certification of photomask linewidth and pitch standards. The recent work is directed at extending the feature sizes on these standards to cover the range from 0.5 to 30 μm, and at doubling the certification accuracy to 0.025 μm. Features with heights larger than approximately 1/4 the wavelength of the illuminating light cannot be modeled as zero-thickness layers as is done for photomasks. The development of models to handle this thick-layer case and to develop practical edge-detection criteria are currently under way at NBS. However, at the present time, it is generally not possible to interpret the image profiles of thick features and thereby measure an accurate linewidth. The basic obstacles that must be overcome to achieve accurate submicron feature size measurements for these features are reviewed, and the prospects for future NBS optical standards for features such as photoresist lines on silicon wafers are assessed. Some suggestions about what to do until these standards become available are given.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., **Metrology In Microlithography**, in VLSI Electronics Microstructure Science, Microlithography for VLSI, N. G. Einspruch, ed., Chapter 7, Vol. 16, pp. 265-317 (Academic Press, 1987).

The advent of very-large-scale and very-high-speed integrated-circuit technologies has had enormous impact on the requirements for accuracy and precision of dimensional metrology. Accurate and precise measurements are needed to improve yield, to ensure that lithographic and critical dimension measurement systems meet specifications, to establish control of fabrication processes, and to relate measurements to theory or to serve as input data to modeling or simulation programs. The push to micrometer and submicrometer feature sizes on larger and larger wafers requires dimensional measurement systems with precision and accuracy which can take up only a small fraction of the error budget of 10% or less allowed in process control. By the gauge maker's rule, the measurement system tolerance must be three to ten times less than the tolerance on the part being manufactured. This book chapter discusses some of the unique requirements which metrology places on optical and scanning electron microscope measurement systems and provides a framework for realistically evaluating the capabilities of a given dimensional-measuring system in the context of the purpose for which the measurement system is to be used.
[Contact: Robert D. Larrabee, (301) 975-2298]

Nyyssonen, D., and Larrabee, R.D., **Submicrometer Linewidth Metrology in the Optical Microscope**, NBS Journal of Research, Vol. 92, No. 3, pp. 187-204 (May-June 1987).

The recent impetus of the semiconductor industry toward submicron feature sizes on integrated circuits has generated an immediate need for measurement tools and standards suitable for these features. Optical techniques have the advantages of being nondestructive and of having high throughput, but the disadvantage of using wavelengths comparable to feature size, which results in complex scattered fields and image structures that are difficult to interpret. Although submicron optical linewidth measurement is possible for 0.3-μm feature sizes, current instrumentation and linewidth standards, particularly for wafers, will have to improve radically in accuracy, as well as in precision, to meet the anticipated needs of the IC industry for

Dimensional Metrology (cont'd.)

submicron dimensional metrology. This paper discusses the effects of inadequate precision and accuracy on process control in IC fabrication and suggests some ways of circumventing these limitations until better instrumentation and standards become available.
[Contact: Robert D. Larrabee, (301) 975-2298]

Postek, M.T., **Submicrometer Dimensional Metrology in the Scanning Electron Microscope**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Vol. 775, Integrated Circuit Metrology, Inspection, and Process Control, pp. 166-171 (1987). [Conference, Santa Clara, California, March 1-6, 1987].

The National Bureau of Standards has initiated a program to develop scanning electron microscope linewidth measurement standards for the integrated-circuit community. This program involves the development of: a scanning electron microscope-based linewidth measurement and standard reference material certification instrument, the necessary electron beam/sample interaction modeling, and the appropriate micrometer and submicrometer artifacts. The basic problems that must be overcome to achieve accurate submicrometer feature size measurements in the scanning electron microscope for these artifacts are reviewed and some suggestions are given of what can be done to "bridge-the-gap" until such standards become available.
[Contact: Michael T. Postek, (301) 975-2299]

Packaging

Recently Published

Kane, D., Moore, B.A., and Walters, E.J., **RADC/NBS International Workshop on Moisture Measurement and Control for Microelectronics (IV)**, NBSIR 87-3588 (June 1987).

This fourth Workshop on Moisture Measurement and Control for Microelectronics served as a forum on moisture and/or materials reliability problems and on ways to control them or measure their extent. Twenty-two presentations are included which contain detailed information on hermeticity measurement and definition; development of standard packages for mass spectrometric calibrations; moisture interaction with various materials; and techniques that can be used to measure moisture in microelectronic packages. It was clear from several presentations in this workshop that a very systematic approach is needed when organic materials are involved; all the variables must be identified and studied one at a time. This is the key to lot-to-lot reproducibility, materials selection, and control; hence a better reliability at the design phase will decrease the need for testing, hence the cost, thus resulting in a greater satisfaction to the customer.
[Contact: E. Jane Walters, (301) 975-2050]

Integrated Circuit Test Structures

Recently Published

Cresswell, M.W., Pessell, N., Betsch, R.J., Linholm, L.W., and Radack, D.J., **Sub-Micron Lithography Characterization Using an Expert System**, Proceedings of the SPIE (The International Society for Optical Engineering, P.O. Box 20, Bellingham, WA 98227), Vol. 775, Integrated Circuit Metrology, Inspection, and Process Control, pp. 304-311 (1987). [Conference, Santa Clara, California, March 1-6, 1987].

This paper describes a test chip, test results, rule-generation techniques, and an expert system for characterizing the performance of a sub-micron lithography process. Examples of test results, data reduction techniques, and expert system output are given. The objective of this

IC Test Structures (cont'd.)

work is to develop a system for automatic process diagnosis.
[Contact: Loren W. Linholm, (301) 975-2052]

Radack, D.J., and Linholm, L.W., **On-Chip Propagation Delay Measurement,** Proceedings of the IEEE 1987 Custom Integrated Circuits Conference, Portland, Oregon, May 4-7, 1987, pp. 579-581.

The accurate measurement of gate propagation delay is needed for increasing the accuracy of simulators and for comparing device designs and evaluating fabrication technologies. A digital circuit is presented which can be used to determine propagation delay of any unclocked circuit element. The circuit contains on-chip logic which allows propagation delay measurement using a low-frequency parametric test system.
[Contact: Loren W. Linholm, (301) 975-2052]

Radack, D.J., Swartz, T.C., Linholm, L.W., and Cresswell, M.W., **A Comprehensive Test Chip for the Characterization of Multi-Level Interconnect Processes,** Proceedings of the 1987 IEEE VLSI Multilevel Interconnect Conference, Santa Clara, California, June 14-17, 1987, pp. 238-244 (1987).

A test chip for the evaluation and characterization of multi-level interconnect processes has been developed. The test chip contains test structures which allow a process engineer to make comparative, quantitative measurements for evaluating the performance of selected processes and equipment. This paper describes the design and testing of selected test structures and presents initial test results.
[Contact: Loren W. Linholm, (301) 975-2052]

Schafft, H.A., **Thermal Analysis of Electromigration Test Structures,** IEEE Transactions on Electron Devices, Vol. ED-34, No. 3, pp. 664-672 (March 1987).

A thermal analysis of a straight-line resistor test structure is used to show how test structure design and test conditions can affect the accuracy of electromigration characterizations of metallizations. Recommendations for the design and use of electromigration test structures are given.
[Contact: Harry A. Schafft, (301) 975-2234]

Schafft, H.A., Staton, T., Mandel, J., and Shott, J., **Reproducibility of Electromigration Measurements,** IEEE Transactions on Electron Devices, Vol. ED-34, No. 3, pp. 673-681 (March 1987).

The reproducibility of median-time-to-failure (t_{50}) measurements was determined in an interlaboratory experiment in which 11 laboratories and a reference laboratory took part. Each laboratory used a method of its choosing to test equivalent samples under the same conditions of current density and oven temperature. The between-laboratory reproducibility of t_{50} measurements normalized to one metallization temperature was dependent on current-density stress: at 1.0 MA/cm^2 it was within 15%, while at 2.5 MA/cm^2 it was generally within 50%. The primary source for variability is in estimating the temperature rise of the test metallization due to joule heating. Recommendations are given for the design and test of electromigration test structures to improve the reproducibility of t_{50} measurements.
[Contact: Harry A. Schafft, (301) 975-2234]

Device Physics and Modeling

Recently Published

Albers, J., **Semiconductor Measurement Technology: Results of the Monte Carlo Calculation of One- and Two-Dimensional Distributions of Particles and Damage: Ion Implanted Dopants in Silicon,** NBS

Device Physics and Modeling (cont'd.)

Special Publication 400-79 (September 1987).

The TRansport of Ions in Matter (TRIM) Monte Carlo code was used to calculate the two-dimensional distributions of particles, primary damage, and electronic and nuclear energy loss for implantation of a line beam source into silicon targets. Approximate two-dimensional distributions of the Frenkel pairs (vacancy-interstitial) created by the primary displacement damage of the target atoms were calculated by means of the Kinchin-Pease equation. These particle, damage, and energy loss distributions allowed for the calculation of the one-dimensional distributions of these quantities for implantation into unmasked targets. A superposition technique was used to construct the two-dimensional particle and approximate Frenkel pairs distributions for implantation past a mask edge. The energetic ions used in the calculations were in two groups: those used as intentional dopants in silicon device fabrication and those which either limited lifetime or acted as gettering sites. The particle distributions were parameterized by means of standard polynomial fitting techniques.
[Contact: John Albers, (301) 975-2075]

Bennett, H.S., **Fundamental Principles for Gallium Arsenide Devices**, Proceedings of the International Symposium on Circuits and Systems, Philadelphia, Pennsylvania, May 4-7, 1987, pp. 12-14 (1987).

Recent advances in physics for submicrometer silicon devices suggest lessons or principles that are valid when numerically simulating the behavior of GaAs devices. These lessons from physics for silicon devices are summarized and their implications for GaAs devices are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., **Submicron Device Physics for Numerical Simulations**, Proceedings of the SPIE (International Society of Optical Engineering, P.O. Box 10, Bellingham, WA 98227-0010), Vol. 763, Physics of Amorphous Semiconductor Devices, pp. 134-140 (1987). [Conference, Los Angeles, California, January 15-17, 1987]

Recent advances in physics for submicron, bipolar-crystalline devices suggest principles that are valid when modeling bipolar devices with noncrystalline regions such as those with polysilicon, polycrystalline silicon, and hydrogenated amorphous silicon emitters. These principles from crystalline device physics are summarized, and their implications for the noncrystalline regions of bipolar devices are given.
[Contact: Herbert S. Bennett, (301) 975-2079]

Bennett, H.S., and Lowney, J.R., **Models for Heavy Doping Effects in Gallium Arsenide**, Journal of Applied Physics, Vol. 62, No. 2, pp. 521-527 (July 15, 1987).

Knowledge of the parameters that describe how the band edges, densities of states, and the effective intrinsic carrier concentrations vary with dopant and carrier densities are essential for reliable predictions from numerical simulations of GaAs/AlGaAs devices and for interpreting optical measurements. Klauder's self-energy method, which is self-consistent, is used to calculate the effects due to the interactions between carriers and dopant ions in GaAs at 300 K. The many-body effects due to the interactions among the carriers themselves, exchange, and correlation are estimated by evaluating expressions similar to those of Abram et al. at 300 K. When densities exceed about 5×10^{16} cm^{-3} in n-type GaAs and 10^{18} cm^{-3} in p-type GaAs, carrier-dopant ion interactions and carrier-carrier interactions become significant and should be included in calculations of band structure changes and of properties which depend on the density of states such as carrier

Device Physics and Modeling (cont'd.)

transport, effective intrinsic carrier concentrations, and coefficients for optical absorption.
[Contact: Herbert S. Bennett, (301) 975-2079]

Gaitan, M., and Mayergoyz, I.D., **Time Perturbation Analysis for the MOS System**, in Fundamental Research on the Numerical Modelling of Semiconductor Devices and Processes, J.J.H. Miller, Ed., pp. 77-83 (Boole, Ireland, 1987) [Proceedings of the First International Workshop on the Numerical Modelling of Semiconductors, Los Angeles, California, December 11-12, 1986]. [Paper also appeared in COMPEL, Vol. 6, No. 22, pp. 77-83 (1987).]

The development of a numerical implementation of the small-signal response of MOS (metal oxide-semiconductor) capacitors, using time perturbation analysis is discussed. The effects of nonconstant doping profiles and interface and bulk traps are included. The model uses Fermi-Dirac statistics to describe the occupancy of the interface and bulk traps. The oxide region is considered to have no mobile carriers, and any fixed oxide charge distribution is modeled as a charge sheet at the $Si-SiO_2$ interface. This technique can be used to find the small signal response of a device from the static solution.
[Contact: Michael Gaitan, (301) 975-2070]

Hefner, A.R., and Blackburn, D.L., **A Performance Trade-Off for the Insulated Gate Bipolar Transistor: Buffer Layer Versus Base Lifetime Reduction**, IEEE Transactions on Power Electronics, Vol. PE-2, No. 3, 194-207 (1987). [Identical paper appeared in PESC '86, Proceedings of the 17th Annual IEEE Power Electronics Specialists Conference, pp. 27-38 (1986).]

A one-dimensional analytic model for the insulated gate bipolar transistor (IGBT), which includes a high-doped buffer layer in the low-doped bipolar transistor base, is developed. The model is used to perform a theoretical trade-off study between IGBTs with and without the buffer layer. The study is performed for devices of equal breakdown voltages, and the critical parameters chosen to "trade-off" are turn-off switching energy loss (related to turn-off time) and on-state voltage, both at a given current. In this model, as in reality, the two critical parameters are varied by 1) adjusting the doping concentration and thickness of a buffer layer included as part of the bipolar transistor base, 2) adjusting the lifetime in the lowly doped bipolar transistor base with no buffer layer included, or by 3) a combination of 1) and 2). The results of the model predict that for equal breakdown voltages an optimized device with a buffer layer has less switching energy loss for a given on-state voltage than an optimized device with no buffer layer.
[Contact: Allen R. Hefner, (301) 975-2071]

Lowney, J.R., and Bennett, H.S., **Limitations of Isotropic Theory of Band-Gap Narrowing in Si and GaAs Devices**, Proceedings of the 1987 IEEE Bipolar Circuits and Technology Meeting, Minneapolis, Minnesota, September 21-22, 1987, pp. 157-159 (1987).

The theory of band-gap narrowing based on uniform material is shown to be invalid for devices with very large doping gradients. Calculations also show that enhanced narrowing results from the built-in field.
[Contact: Jeremiah R. Lowney, (301) 975-2048]

Radiation Effects

Released for Publication

Singh, G., Galloway, K.F., and Russell, T.J., **Temperature Induced Rebound in Power MOSFETs.**

Enhancement mode n-channel power MOSFETs

Radiation Effects (cont'd.)

were investigated for rebound. They received 300 krad(Si) gamma dose under positive gate bias with source and drain grounded. The irradiated transistors were thermally annealed with all terminals shorted or under positive gate bias with drain and source shorted, at temperatures from 60°C to 150°C. Threshold voltage rebound was observed for some transistor types under certain experimental conditions.
[Contact: Thomas J. Russell, (301) 975-2073]

Suehle, J.S., Russell, T.J., and Galloway, K.F., **Interface Trap Effects on the Hot-Carrier-Induced Degradation of MOSFETs During Dynamic Stress.**

Foundry and hardened n-channel MOSFETs were stressed with dynamic AC pulses and with static DC voltages. The pre-radiation hot-carrier-induced degradation is much more severe in the dynamic case than in the static case for the hardened devices. The data suggest that the pre-radiation hot-carrier degradation is strongly influenced by the relative density of interface traps and by the pulse structure. The post-radiation hot-carrier degradation is mainly influenced by the amount of radiation-induced fixed oxide charge.
[Contact: John S. Suehle, (301) 975-2247]

Insulators and Interfaces

Recently Published

Carver, G.P., Novotny, D.B., and Kopanski, J.J., **An Innovative Measurement of Specific Contact Resistivity Confirms Lower Aluminum-Silicon Contact Resistance,** Proceedings of the 1987 IEEE VLSI Multilevel Interconnect Conference, Santa Clara, California, June 14-17, 1987, pp. 337-343 (1987).

New accurate data prove that the value of the aluminum-silicon specific contact resistivity is much smaller than the value determined previously by two-level planar contact resistor structures. The new data were obtained using an innovative method based upon small, geometrically well-defined contacts, for which the silicon spreading resistance can be calculated self-consistently. In this method, the total series resistance is measured at a contact window in an oxide layer to a silicon wafer. Unlike two-level planar structures, lateral and vertical current crowding effects in the metal layer are measured separately and are not involved directly in modeling the contact resistance. Using this new method, values of the specific contact resistivity between an aluminum alloy containing 1.5% silicon and silicon wafers were measured for p-type silicon resistivities in the range from 0.006 to 25 ohm-cm and for n-type silicon resistivities in the range from 0.0014 to 0.0026 ohm-cm. The specific contact resistivity values we obtained are about five times smaller than values reported from two-level planar structures, suggesting that aluminum may be useful for contact dimensions as small as 0.5 μm on a side. With the new results, multilevel conductor systems can be designed for optimal performance.
[Contact: Gary P. Carver, (301) 975-2091]

Other Semiconductor Metrology Topics

Released for Publication

Novotny, D.B., **Emission Spectra of a Diazide Photoresist Initiator and Exposure Reciprocity.**

The emission spectra of an initiator typical of those used in negative photoresists, namely, 2,6 bis-(p-azidobensilidene)-4-ethylcyclohexanone, were investigated. It is shown that the assumption that the large absorption band in negative photoresist is due to a single transition state is not valid. It is composed of narrow states which, in turn, implies that reciprocity failure and loss of sensitivity would occur at lower intensities than predicted. It is

Other Semiconductor Topics (cont'd.)

concluded that rapid quenching from the excited states is occurring.
[Contact: Donald B. Novotny, (301) 975-2699]

Recently Published

Bouldin, C.E., Forman, R.A., Bell, M.I., Donovan, E.P., and Hubler, G.K., **EXAFS Measurements of Ion and Implanted Amorphous Surface Layers**, Proceedings of the SPIE (International Society of Optical Engineering, P.O. Box 10, Bellingham, WA 98227-0010), Vol. 690, Optoelectronic Applied Sciences and Engineering, pp. 45-51 (1986). [Conference, San Diego, California, August 17, 1986]

EXAFS measurements of ion-damaged amorphous Ge (a-Ge) show that low-temperature annealing causes a structural relaxation in the as-implanted a-Ge. It is found that there is a sharpening of the first shell in the radial distribution but no change occurs in the first-shell distance or coordination number. No higher shells in the radial distribution are observed either before or after annealing, indicating that these shells remain highly disordered. The observed structural relaxation is an amorphous-amorphous transition; no nucleation of microcrystals takes place. EXAFS measurements are made using conversion electron detection (CEEXAFS), which is essentially total electron yield detection in ambient conditions, allowing the EXAFS measurements to be near-surface sensitive with a sampling depth of 600 to 800 Å.
[Contact: Charles E. Bouldin, (301) 975-2946]

Zaghloul, M.E., **An Overview of Testability Measures in the Design of Digital Integrated Circuits**, Semicustom Design Guide, pp. 98-108 (1987).

This paper is an overview of testability measures in the design of digital integrated circuits. Commercial testability algorithms are described and compared. Recent developments on testability measures which enhance the role of testability are discussed.
[Contact: Loren W. Linholm, (301) 975-2052]

FAST SIGNAL ACQUISITION, PROCESSING, AND TRANSMISSION

Waveform Metrology

Released for Publication

Turgel, R.S., **Phase Meter Calibration at NBS.**

To provide a phase meter calibration service, a phase angle calibration standard has been developed at NBS. This standard is a signal generator with two sinusoidal outputs and uses direct digital synthesis to generate the signals. The phase angle between the two sinusoids is determined by the input parameters in the calculation of the sets of digital values from which the analog output is synthesized. An auto-zero compensation mode corrects for residual phase differences in the two output channels. The phase resolution is better than 0.002 deg over a frequency range from 2 Hz to 5 kHz and 0.005 deg from 5 kHz to 50 kHz.

Phase meter calibration data are fitted to a linear model from which appropriate corrections for the phase meter readings can be derived. Statistical treatment of the data provides an estimate of the uncertainty of the corrected phase meter readings relative to the phase angle calibration standard.
[Contact: Raymond S. Turgel, (301) 975-2420]

Recently Published

Bell, B.A., **A Report on the NBS/CEEE Survey of Electronic Measurement Needs Below 10 MHz**, Proceedings of the National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp.

Waveform Metrology (cont'd.)

75-1 - 75-14.

This paper describes the results of a recent survey conducted by the Electrosystems Division of the Center for Electronics and Electrical Engineering (CEEE) at the National Bureau of Standards (NBS). A summary analysis is provided of the data obtained on questions concerning (1) critical electrical quantities and associated instrumentation and devices, (2) automatic test equipment (ATE)/complex measurement systems, and (3) conducted electromagnetic interference.
[Contact: Barry A. Bell, (301) 975-2402]

Lawton, R.A., and Meyer, K., **Waveform Standards for Electrooptics: A Pulse Duration Comparison**, IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-35, No. 4, pp. 450-453 (April 1987).

A transfer standard has been developed for use in comparing the measurement capability of the Automatic Pulse Measurement System (APMS) at the National Bureau of Standards to that of recently developed electrooptic samplers. This transfer standard is a comb generator driven by a 90-MHz sine wave. Using this standard, measurements were made of the pulse waveform of a comb generator output with both the APMS and an electro-optic sampler. A comparison was then made of the pulse duration (full width at half maximum) obtained in the two waveform measurements. The result was a duration of 102 ps as measured by the APMS and 112 ps as measured by the electro-optic sampler. The signal-to-noise ratio at the comb generator input was improved over that of previous measurements, and a correction for pulse broadening was made to achieve this result. The pulse broadening was caused by the impedance mismatch between the sampler and the transmission system (50 Ω).
[Contact: Robert A. Lawton, (303) 497-3339]

Oldham, N.M., **AC Voltage and Current Measurements**, MAPAN, Journal of Metrology Society of India, Vol. 1, No. 3, pp. 17-18 (1986).

Definitions and various measurement techniques for the measurement of ac voltage and current are given.
[Contact: N. Michael Oldham, (301) 975-2408]

Oldham, N.M., Laug, O.B., and Waltrip, B.C., **Digitally-Synthesized Power Calibration Source**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 341-346 (June 1987) [CPEM 86 Proceedings issue].

A digitally synthesized source of "phantom" power for calibrating electrical power and energy meters is described. Independent sources of voltage, current, and phase angle are programmable between 0 and 240 V, 0 and 5 A, and 0 and 360 deg, respectively. The accuracy of the active and reactive power is estimated to be within ±100 ppm of the full scale apparent power (volt-amperes).
[Contact: N. Michael Oldham, (301) 975-2408]

Oldham, N.M., and Parker, M.E., **NBS Calibration System for AC Voltage**, Proceedings of the 1987 National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp. 47-1 - 47-6.

An automatic system for calibrating high accuracy ac voltmeters and calibrators is described. The system relies on measurements using coaxial thermal voltage converters to achieve ac-voltage uncertainties of 5 to 150 ppm from 0.01-600 volts over the frequency range of 10 Hz to 1 MHz. Specialized hardware and measurement techniques make it possible to achieve these uncertainties in test periods of approximately one minute. Random errors introduced by the system are typically less than 2 ppm (one standard deviation).
[Contact: N. Michael Oldham, (301) 975-2408]

Waveform Metrology (cont'd.)

Oldham, N.M., Parker, M.E., Young, A., and Smith, A.G., **A High Accuracy, 10 Hz - 1 MHz Automatic AC Voltage Calibration System,** Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 279-281 (April 1987).

An automatic system for calibrating high-accuracy ac voltmeters and calibrators is described. The system is based on traditional coaxial thermal voltage converters to provide measurement uncertainties of 5 to 20 ppm in the audio frequency range and 5 to 150 ppm over the full range from 10 Hz to 1 MHz. Specialized hardware and measurement techniques make it possible to achieve these uncertainties in test periods of approximately one minute. Random errors introduced by the system are typically less than 2 ppm (one standard deviation).
[Contact: N. Michael Oldham, (301) 975-2408]

Schoenwetter, H.K., **Design and Characterization of a Programmable Step Generator with Very Fast Settling Performance,** IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 428-432 (June 1987) [CPEM 86 Proceedings issue].

A pulse generator for testing the step response of waveform recorders is described. The initial and final levels of voltage steps are each programmable within the range of ±1 V for a 50-Ω termination. Voltage steps within this range settle to within ±0.2 and ±0.1 percent of full-scale range in approximately 4 and 6 ns, respectively. The 10-90 percent transition duration is approximately 1.7 ns.
[Contact: Howard K. Schoenwetter, (301) 975-2414]

Souders, T.M., and Flach, D.R., **Accurate Frequency Response Determinations from Discrete Step-Response Data,** IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 433-439 (June 1987) [CPEM 86 Proceedings issue].

An approach is presented for quickly obtaining the complex frequency response of a system from sampled step-response data. Digital signal processing techniques are used extensively. An analysis of errors resulting from sampling, quantization, first differencing, and record length is included.
[Contact: T. Michael Souders, (301) 975-2406]

Cryoelectronic Metrology

Released for Publication

Kautz, R.L., and Lloyd, F.L., **Precision of Series-Array Josephson Voltage Standards.**

Comparison of two series-array Josephson voltage standards operated at over 1 V shows that they differ in voltage by less than two parts in 10^{17}.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

McGrath, W.R., Richards, P.L., Face, D.W., Prober, D.E., and Lloyd, F.L., **Accurate Experimental and Theoretical Comparisons Between SIS Mixers Showing Weak and Strong Quantum Effects.**

We have made a systematic study of the gain and noise in superconductor-insulator-superconductor (SIS) mixers employing a Ta-based, Nb-based and Pb-alloy-based tunnel junctions. These junctions displayed both weak and strong quantum effects at a signal frequency of 33 GHz. The effects of energy gap sharpness and sub-gap current were investigated and are quantitatively related to mixer performance. Detailed comparisons are made of the mixing results with the predictions of the Tucker theory. We have measured mixer performance with a novel test apparatus which is accurate enough to allow for the first detailed tests of theoretical

Cryoelectronic Metrology (cont'd.)

noise predictions. We find that the Tucker theory underestimates the mixer noise temperature by a factor of about 2 for all of our mixers. In addition, predicted values of available mixer gain are in reasonable agreement with experiment when quantum effects are weak. However, as quantum effects become strong, the predicted gain diverges to infinity which is in sharp contrast to the experimental results. Predictions of coupled gain do not always show such divergences.
[Contact: Frances L. Lloyd, (303) 497-3254 or -3988]

Zimmerman, J.E., Beall, J.A., Cromar, M.W., and Ono, R.H., **Equivalent Flux Noise in a $YBa_2Cu_3O_x$ rf SQUID**, to be published in the Proceedings of the 18th International Conference on Low Temperature Physics, Kyoto, Japan, August 20-26, 1987.

We have measured the noise in flux-locked radiofrequency SQUIDs made of bulk $YBa_2Cu_3O_x$ both in a He-cooled cryostat and in liquid nitrogen (LN_2). Our best results at 75 K show a spectral density of the equivalent flux noise equal to 4.5 s 10^{-4} $\phi_0/\sqrt{Hz}$. There is considerable variation in the performance of SQUIDs made from nominally similar material.
[Contact: James E. Zimmerman, (303) 497-5102]

Recently Published

Hamilton, C.A., Kautz, R.L., Lloyd, F.L., Steiner, R.L., and Field, B.F., **The NBS Josephson Array Voltage Standard**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 258-261 (June 1987).

A Josephson voltage standard based on a series array of 2076 junctions is described. When irradiated with a 15-mW signal at a frequency of 96 GHz, the array produces 15,000 quantized levels between -1.5 and 1.5 V. Initial results on high-precision comparisons with a Zener reference standard are given.
[Contact: Clark A. Hamilton, (303) 497-3740 or -3988]

Kautz, R.L., **Global Stability of Phase Lock Near Chaotic Crisis in the RF-Biased Josephson Junction**, Journal of Applied Physics, Vol. 62, No. 1, pp. 198-211 (July 1, 1987).

The global stability of phase lock in the radiofrequency-biased Josephson junction is studied through digital simulations. Global stability is determined by calculating the lifetime of the phase-locked state in the presence of thermal noise. This lifetime, the mean time required for thermal noise to induce a 2π phase slip, increases exponentially with inverse temperature in the limit of low temperatures, and the low-temperature asymptote can be parameterized in terms of an activation energy ε and an attempt time τ_o. The activation energy is a useful measure of global stability for both periodic and chaotic phase-locked states. The behavior of ε and τ_o is studied over a range of critical current densities which take the system from a region of harmonic motion through a period-doubling cascade and into a region of phase-locked chaotic behavior which is ended by a chaotic crisis. At the crisis point, the activation energy goes to zero and the attempt time goes to infinity. The results are used to determine the optimum critical current density for series-array voltage standards.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Kautz, R.L., Hamilton, C.A., and Lloyd, F.L., **Series-Array Josephson Voltage Standards**, IEEE Transactions on Magnetics, Vol. MAG-23, No. 2, pp. 883-890 (March 1987).

Series arrays typically including 1500 Josephson junctions driven at 90 GHz have been used to generate quantized reference voltages in excess of 1 V. Such standards simplify the procedure

Cryoelectronic Metrology (cont'd.)

and reduce the measurement uncertainties in the calibration of electrochemical cells.
[Contact: Richard L. Kautz, (303) 497-3391 or -3988]

Ono, R.H., Cromar, M.W., Kautz, R.L., Soulen, R.J., Colwell, J.H., and Fogle, W.E., **Current-Voltage Characteristics of Nanoampere Josephson Junctions**, IEEE Transactions on Magnetics, Vol. MAG-23, No. 2, pp. 1670-1673 (March 1987) [Proceedings of the 1986 Applied Superconductivity Conference, Baltimore, Maryland, Sept. 28-Oct. 3, 1986].

We have studied the current-voltage (I-V) characteristics of small-area tunnel junctions at temperatures below 1 K. The junctions were made in an edge geometry with an Nb base electrode and had areas less than 0.05 μm^2 and critical currents in the nanoampere range. Although the measured I-V characteristics resemble those of ordinary hysteretic junctions, the supposed zero-voltage portion of the curve proved to have a finite slope and to deviate from zero voltage. For these junctions, it is apparently possible for occasional 2π phase slips to occur without switching to the usual voltage state. This behavior can be explained either by macroscopic quantum tunneling or by a model in which the effective shunt conductance of the junction is frequency-dependent.
[Contact: Michael W. Cromar, (303) 497-5375]

Peterson, R.L., **Sinusoidal Response of dc SQUIDs for rf Power Measurements**, NBS Journal of Research, Vol. 92, No. 4, pp. 253-259 (July-August 1987).

Current, power, and attenuation measurements with radiofrequency Superconducting QUantum Interface Devices (SQUIDs) are based on the fact that the voltage from the microwave readout circuit can be made a nearly sinusoidal function of the magnetic flux threading the SQUID. We point out here that an asymmetric dc SQUID with sufficiently low inductance can achieve a very sinusoidal output voltage with good modulation depth. The spectral purity of the sinusoid can be substantially better than that obtained with rf SQUID systems. The purity improves with increasing asymmetry of the junction critical currents, and decreasing values of the LI_c product, where L is the SQUID inductance and I_c is the smaller of the critical currents. Results of several calculations are presented. Substantial improvement in SQUID methods of rf current, power, or attenuation measurement may thus be possible with use of such dc SQUIDs.
[Contact: Robert L. Peterson, (303) 497-3750 or -3227]

Zimmerman, J.E., Beall, J.A., Cromar, M.W., and Ono, R.H., **Operation of a Y-Ba-Cu-O rf-SQUID at 81 K**, Applied Physics Letters, Vol. 51, No. 8, pp. 617-618 (August 24, 1987).

An rf superconducting quantum interference device (SQUID) has been made from bulk Y-Ba-Cu-O. The device displays quantum interference effects and operates with useful signal levels up to 81 K. The SQUID is formed from a ring of Y-Ba-Cu-O which is broken in the cryogenic environment and then recontacted. Estimates of the SQUID noise performance are given.
[Contact: James A. Beall, (303) 497-5989]

Antenna Metrology

Released for Publication

FitzGerrell, R.G., and Treado, M.J., **Mobile Antennas.**

This document establishes minimum performance requirements and methods of test for mobile antennas mounted on vehicles used by law enforcement agencies, and deals with antenna characteristics that determine the suitability and effectiveness of antennas for law enforcement use. The following four law

Antenna Metrology (cont'd.)

enforcement frequency bands are considered: 25 to 50 MHz, 150 to 174 MHz, 400 to 512 MHz, and 806 to 866 MHz. This standard supersedes NILECJ-STD-0205.00, Mobile Antennas dated May 1974.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Francis, M.H., and Hill, D.A., **Out-of-Band Response of Array Antennas.**

The National Bureau of Standards has examined the out-of-band response of array antennas from both a theoretical and experimental point of view. From theory, the out-of-band response of an antenna is found to depend primarily on two factors: the antenna input impedance and the antenna directivity. From experiment, it is found that for most practical purposes the out-of-band response of an antenna can be estimated from a measurement of the antenna input reflection coefficient alone. If the reflection coefficient is low, the antenna response will be good; if the reflection coefficient is high, the antenna response will be poor.
[Contact: Michael H. Francis, (303) 497-5873]

Kanda, M., **A Microstrip Patch Antenna as a Standard Transmitting and Receiving Antenna.**

This paper discusses the possibility of employing a microstrip patch antenna as a standard transmitting antenna. The intrinsic properties of the substrate used for the antenna are determined by caretul impedance measurements. The experimental results indicate that the transmitting characteristics of a microstrip antenna can be theoretically determined from its geometry. The microstrip patch antenna discussed here is physically small (20 cm^2 for 450 MHz) and can be well matched to a power delivery system (SWR = 1.17).
[Contact: Motohisa Kanda, (303) 497-5320]

Muth, L.A., **Experimental Study of Interpanel Interactions at 3.3 GHz,** to be published in the Proceedings of the 9th Annual Meeting and Symposium of the Antenna Measurement Technique Association (AMTA), Seattle, Washington, September 28-October 2, 1987.

The results of measurements on experimental array panels in various configurations are reported. In each of the configurations, both the near-field and portside signals are measured to study the interaction between array panels. These array panels consisted of 256 microstrip radiating elements. In particular, the effects of open-circuited array panels on the radiation pattern of a single panel are observed both in the near field and in the far field. It is found that interpanel scattering is the main mechanism of interaction between panels, rather than reradiation of signals received from adjacent panels. The effects of scattering are observable at the -50 dB level.
[Contact: Lorant A. Muth, (303) 497-3603]

Repjar, A.G., Newell, A.C., and Francis, M.H., **Accurate Determination of Planar Near-Field Correction Parameters for Linearly Polarized Probes.**

The receiving patterns of two probes, for both amplitude and phase, must be known and utilized to determine accurately the complete far field of an antenna from near-field measurements. The process of incorporating the probe characteristics in the far-field computation is referred to as "probe correction." When the antenna to be measured is nominally linearly polarized, the measurements are more accurate and efficient if nominally linearly polarized probes are used. Further efficiency is obtained if only one dual-polarized probe is used to allow simultaneous measurements of both components. It should be noted, however, that a single-port probe can be rotated by 90 deg to obtain the second component. A procedure used by the National Bureau of Standards for accurately determining the

Antenna Metrology (cont'd.)

plane-wave receiving parameters of both single- and dual-port linearly polarized probes is described. Examples are presented and the effect of these probe-receiving characteristics in the calculation of the parameters for the antenna being measured under test is demonstrated using appropriate planar near-field theory.
[Contact: Andrew G. Repjar, (303) 497-5703]

Repjar, A.G., Newell, A.C., and Tamura, D.T., **Extrapolation Range Measurements for Determining Antenna Gain and Polarization**, to be published as NBS Technical Note 1311.

The extrapolation range measurement technique for determining the power gain and polarization of antennas at reduced range distances is described. It is based on a generalized three-antenna approach and does not require quantitative a priori knowledge of the antennas. During the past decade, it has been extensively used by the National Bureau of Standards [Boulder, Colorado] to calibrate antenna gain standards for industry and other agencies within ±0.1 dB. To help one understand how calibrations of this accuracy are achieved, the extrapolation range description includes discussions on the required theory, the measurement procedures, the range configuration and instrumentation, the errors, and some measurement examples. Recent extensions of the extrapolation method required for swept/stepped frequency gain calibrations and for corrections to reduce ground reflection effects are also presented.
[Contact: Andrew G. Repjar, (303) 497-5703]

Wittmann, R.C., **Spherical Wave Operators and the Translation Formulas.**

Translation formulas for both scalar and vector spherical wave solutions of the Helmholtz equation are developed, in a straightforward and relatively uncomplicated manner, emphasizing powerful differential operator techniques. Additionally, the expansion coefficients are given in compact integral or differential operator forms useful for analytic investigation.
[Contact: Ronald C. Wittmann, (303) 497-3326]

Recently Published

Newell, A.C., **The Effect of Random Errors in Planar Near-Field Measurements**, Proceedings of the 1986 IEEE Antenna and Propagation Society Symposium, Philadelphia, Pennsylvania, June 8-13, 1986, pp. 196-198 (1987).

Equations have previously been derived to predict the effect of systematic errors in planar near-field measurements. Similar expressions for random errors have not been generally available, although computer simulation has been used to study some specific cases. In this report, simple general expressions are derived to predict the effect of random errors that require only minimal information about the antenna and the error distributions.
[Contact: Allen C. Newell, (303) 497-3743]

Noise Metrology

Released for Publication

Daywitt, W.C., **Horn Design Equations for the NBS Horn-Type Noise Standards**, to be published as NBSIR 87-3073.

Equations are given for calculating the interior dimensions of the horn pickup in the NBS millimeter-wave noise standards. The equations are used to design the horn for negligible internal horn reflections, resulting in an accurate calculation of the horn attenuation.
[Contact: William C. Daywitt, (303) 497-3720]

Microwave & Millimeter-Wave Metrology

Released for Publication

Hoer, C.A., **Some Questions and Answers**

Microwave & Millimeter-Wave (cont'd.)

Concerning Air Lines as Impedance Standards.

This paper attempts to answer a number of questions that arise when using one or more lengths of precision transmission line to calibrate a dual six-port ANA, questions such as: 1) How important is the quality of the test port relative to that of the line? 2) What type connectors should the line standards have? 3) What are the advantages of using two lines instead of one line and a through connection when test port imperfections are considered? 4) How many lines are optimum from a quality control point of view? 5) What should the lengths be?

The answers to these questions appear to be: 1) The quality of the line is much more important than that of the test port. A perfect line will calibrate out most imperfections in the test port. An example is given where 75-Ω test ports are calibrated with 50-Ω lines, and then used to measure Γ relative to 50 Ω with very little error. 2) Greatest accuracy is achieved with line standards having male connectors. 3) Two lines get rid of many test port imperfections that one line cannot. 4) Three lines will show up a problem if one line is bad. Five lines will identify which line is bad. Five is probably optimum. 5) There may not be an optimum for the actual lengths of a set of lines, but there does appear to be an optimum difference in the lengths.
[Contact: Cletus A. Hoer, (303) 497-3705]

Recently Published

Daywitt, W.C., **Complex Admittance of a Lossy Coaxial Open Circuit with a Hollow Center Conductor**, Metrologia, Vol. 24, pp. 13-22 (1987).

The reflection coefficient and complex discontinuity admittance of a coaxial open circuit with a hollow center conductor are derived from fields correct to first order in the skin depth. Results show an admittance terminating the line at the plane of the discontinuity and consisting of a resistance in parallel with a capacitive reactance. The first-order fields are also used to derive equations for the characteristic admittance, series impedanc and shunt admittance of the line. These equations include terms neglected in the well-known expressions used to calculate the line parameters, enabling error limits to be assigned to the latter.
[Contact: William C. Daywitt, (303) 497-3720]

Larsen, N.T., **Microwave Power Standards**, Proceedings of the National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp. 34-1 - 34-7.

A general review of the history and present status of the microwave power standards in use at the National Bureau of Standards (NBS) is presented. The standards are calorimeters, and the quantity measured is "effective efficiency." The calibration services are based on these standards. The design and evaluation of these standards are discussed.
[Contact: Neil T. Larsen, (303) 497-3711]

Optical Fiber Metrology

Released for Publication

Li, X., and Gallawa, R.L., **Calibrated Optical Fiber Power Meters: Errors due to Variations in Connectors.**

We discuss the potential for errors in the measurement of optical fiber power using a calibrated power meter with connectors of various types and from different vendors. Data are given on the error and standard deviation due to biconic connectors from a limited number of vendors. We speculate that the error is due to reflecting surfaces on the

Optical Fiber Metrology (cont'd.)

connector end. To confirm the hypothesis, we tested two connectors whose reflective ends have noticeable differences. The data illustrate the differences seen among connectors. Our data indicate that a user should expect measurement error in most cases. We issue a call for caution based on the results.
[Contact: Robert L. Gallawa, (303) 497-3830]

Li, X., and Gallawa, R.L., **Potential Errors in the Use of Optical Fiber Power Meters.**

We discuss the potential for errors associated with the measurement of optical power in a field environment. Errors can arise because field use is often inconsistent with the calibration method. Errors may be due to the use of connectors of different types and due to variation amongst vendors for a given connector type. We consider two of the most popular connector types and discuss their effect on power measurements.
[Contact: Robert L. Gallawa, (303) 497-3761]

Recently Published

Danielson, B.L., and Whittenberg, C.D., **Guided-Wave Reflectometry with Micrometer Resolution** [Original title: A New Method for High Resolution Reflectometry], Applied Optics, Vol. 26, No. 14, pp. 2836-2842 (July 15, 1987).

We describe a new type of optical reflectometry which is useful in testing single-mode lightguide systems. This technique uses a scanning Michelson interferometer in conjunction with a broadband illuminating source and cross-correlation detection. High resolution is achieved through the limited coherence of the backscattered radiation. With this approach it is possible to distinguish scattering centers separated by only a few micrometers. In some cases loss may be estimated for components in the transmission path of a test lightguide. The basic principles of this diagnostic technique, along with some performance characteristics, are illustrated for an all-fiber reflectometer. We also discuss several laboratory applications which serve to demonstrate the resolution capabilities of this measurement concept.
[Contact: Bruce L. Danielson, (303) 497-5620]

Electro-Optic Metrology

Released for Publication

Day, G.W., **Materials and Configurations for Faraday Effect Electric Current and Magnetic Field Sensors**, to be published in the Proceedings of the International Conference on Optical Fiber Sensors (OFS88), New Orleans, Louisiana, January 1988.

Materials and design techniques applicable to a wide range of Faraday rotation sensor requirements, many of which could not be solved with all-fiber designs, are described.
[Contact: Gordon W. Day, (303) 497-5204]

Korde, R., and Geist, J., **Quantum Efficiency Stability of Photodiodes**, Applied Optics.

The stability of the quantum efficiency of inversion layer, phosphorus diffused (n-conductivity type on p) and boron diffused (p on n) photodiodes has been investigated. Unsatisfactory silicon-silicon dioxide interfaces, latent recombination centers in the diffused layers, and moisture absorption by the device were identified as possible causes of instability. Diodes were fabricated using processes in which these sources of instability were carefully controlled. The resulting diodes were subjected to long periods of intense ultraviolet irradiation, baking at 110°C, and baking at 100°F in a 100% relative humidity environment in an attempt to accelerate any instabilities

Electro-Optic Metrology (cont'd.)

that might be brought on by normal use and handling. The external quantum efficiency of the diodes was measured before, and at intervals during, their environmental stressing. Diodes made by older procedures, in which some important parameters affecting stability were not controlled, were included in the study for comparison. The major result of this work is the demonstration that n on p photodiodes are inherently more stable than p on n types in the ultraviolet and blue spectral regions, but that stable p on n devices can also be produced with sufficient care.
[Contact: Jon Geist, (301) 975-2066]

Larson, D.R., and Phelan, Jr., R.J., **A Fast Optical Detector Deposited on Dielectric Channel Waveguides.**

We have fabricated a thin-film optical detector for detecting short optical pulses propagating in channel waveguides. The detectors show response times of 200 ps full-width-at-half-maximum amplitude when illuminated by guided, subpicosecond optical pulses.

The detectors are formed by depositing hydrogenated amorphous silicon (a-Si:H) directly on the dielectric channel waveguides. Back-to-back Schottky photodiodes are then formed when interdigitated chromium-gold metal contacts are deposited on the a-Si:H.
[Contact: Donald R. Larson, (303) 497-3440]

Larson, D.R. and Phelan, Jr., R.J., **Picosecond Pulse Response from Hydrogenated Amorphous Silicon (a-Si:H) Optical Detectors on Channel Waveguides**, to be published in the Proceedings of the SPIE, Integrated Optical Circuit Engineering, Vol. 835.

We have fabricated high-speed optical detectors on channel waveguides formed by both potassium ion-exchange in glass and titanium diffusion in lithium niobate. These new waveguide detectors show response times of 200 picoseconds full-width-at-half-maximum amplitude when illuminated with subpicosecond optical pulses. The detectors consist of back-to-back Schottky photodiodes formed by chromium-gold metal contacts on hydrogenated amorphous silicon (a-Si:H). Using interdigitated metal contacts with the contact separation and semiconductor film thickness dimensions close to a micrometer results in detectors that are both fast and efficient.
[Contact: Donald R. Larson, (303) 497-3440]

Recently Published

Day, G.W., Hale, P.D., Deeter, M., Milner, T.E., Conrad, D., and Etzel, S.M., **Limits to the Precision of Electro-Optic and Magneto-Optic Sensors**, Optical Power Line Voltage and Current Measurement Systems, Electric Power Research Institute Report EPRI EL-5431, Vol. 1 (September 1987). [Also appeared with the same title, introduction, and short abstract as NBS Technical Note 1307 (March 1987).]

This study began with a central question, "What precision can be achieved with an electro-optic voltage sensor or a magneto-optic current sensor?" The answer has been pursued in numerous ways, through an investigation of the basic properties of materials and components, both as reported in the literature and new data generated in our laboratory; through attempts to demonstrate the feasibility of overcoming certain limitations in the properties of components; through analysis of some fundamental limitations, through the proposal of new or refined designs, and through discussions with numerous other investigators.

It was concluded that ease of obtaining high precision (in a power systems context) is not included among the advantages of using optical sensors for measurement of electromagnetic quantities. The principal difficulty was that sensors have to maintain their calibration

Electro-Optic Metrology (cont'd.)

over broad temperature ranges (at least 100 C) without the possibility of temperature stabilization. Specifically, using relatively standard approaches and an appropriate definition of precision, a precision not better than about ±1 percent can be expected. Achieving that level will require wise choices of materials, components, and design, and numerous suggestions are offered.

Judgments about the commercial viability of such devices are left to those more expert in that subject. However, worst-case situations are encountered infrequently, and therefore represent pessimistic assessments of performance in real applications. Also, the other advantages of optical sensors may in some applications be dominant considerations. Safety is one example.

Using passive temperature compensation techniques may improve the precision of optical sensors by a desired order of magnitude. Several have been examined analytically, and the authors suggest that they be investigated further. Other approaches, including temperature compensation by measurement and adjustment, could be considered, but are not discussed here. The development of all-fiber or nearly all-fiber sensors could provide very simple, low-cost measurements, even if the highest precision is not achieved, and further work in this area is suggested.
[Contact: Gordon W. Day, (303) 497-5204]

Geist, J., **Photodiode Quantum Efficiency and Spectral Responsivity Self-Calibration**, Proceedings of the IEEE Instrumentation and Measurement Technology Conference, Boston, Massachusetts, April 27-29, 1987, pp. 75-79.

High-quality silicon photodiodes can be used as primary radiometric standards in the visible portion of the radiometric spectrum. The physical basis for their use as standards, and their performance in areas pertinent to their use as standards, is reviewed.
[Contact: Jon Geist, (301) 975-2066]

Geist, J., **Recent Improvements in Radiometric Accuracy Based on New Detector Technology**, Remote Sensing of Environment, Vol. 22, pp. 127-129 (1987).

Until recently, the best accuracy achievable in the measurement of radiometric properties was limited by the accuracy of the ultimate radiometric standard to which the measurement could be traced. Since about 1980, however, there have been such dramatic improvements in the accuracy of detector-based standards that this is no longer the case. These new radiometric standards are briefly reviewed in this paper, with emphasis on the intercomparisons that demonstrate their accuracy.
[Contact: Jon Geist, (301) 975-2066]

Korde, R., and Geist, J., **Stable, High Quantum Efficiency, UV-Enhanced Silicon Photodiodes by Arsenic Diffusion**, Solid-State Electronics, Vol. 30, No. 1, pp. 89-92 (1987).

Very high quantum efficiency, UV-enhanced silicon photodiodes have been developed by arsenic diffusion into p-type silicon as an alternative to the inversion layer photodiodes commonly used in precise radiometric and spectroscopic measurements. The fabricated diodes had an unbiased internal quantum efficiency that was 100% from 350 to 550 nm, and that exceeded 100% at shorter wavelengths. A typical responsivity at 200 nm was 0.1 A/W. No degradation in responsivity was detected anywhere in the 200- to 1100-nm range when these devices were exposed to 20 mW/cm^2 of 254-nm radiation for 60 days. Thus the theoretical maximum value of internal quantum efficiency for a diffused photodiode appears to have been achieved in the UV and short wavelength visible, without compromising the diode's long-term stability. This is marked contrast to older types of diffused photodiodes,

Electro-Optic Metrology (cont'd.)

exhibited a spectral response vs. flux characteristic that changed considerably with UV exposure.
[Contact: Jon Geist, (301) 975-2066]

Peterson, R.L., **Numerical Study of Currents and Fields in a Photoconductive Detector** [previously titled "Numerical Study of Currents and Fields in a Semiconducting Optical Detector"], IEEE Journal of Quantum Electronics, Vol. QE-23, No. 7, pp. 1185-1192 (July 1987).

A numerical study of the current, field, and carrier density distributions within a photoconductive detector is presented. The photodetector, an interdigitated Schottky barrier diode, is made with metallic fingers of alternating voltage bias on a thin semiconductor layer grown on a transparent dielectric substrate. The Poisson and continuity equations for electrons and holes are treated in two dimensions. A modified successive line overrelaxation method, faster than the capacitance matrix method, is developed as the Poisson solver. A simple alternative to the Scharfetter-Gummel treatment of current density is also introduced. We investigated steady-state cases with and without optical illumination, and transient responses to picosecond optical pulses. The steady-state current shows near saturation with increasing voltage, as observed experimentally. The calculated typical response of the silicon detector to a picosecond optical pulse is a current pulse lasting on the order of 10 ps.
[Contact: Robert L. Peterson, (303) 497-3750 or -3227]

Complex Testing

Recently Published

Stenbakken, G.N., and Souders, T.M., **Test Point Selection and Testability Measures via QR Factorization of Linear Models**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 406-410 (June 1987). [Paper given at the 29th Midwest Symposium on Circuits and Systems, Lincoln, Nebraska, August 10-12, 1986].

An efficient algorithm is presented for selecting test points for use in applications such as calibration and fault diagnosis of electronic networks. The algorithm, based on QR factorization of the circuit sensitivity matrix, minimizes the prediction or estimation errors which result from random measurement error. A definition of testability based on the concept of minimum estimation error is also introduced. Practical examples are given.
[Contact: Gerard N. Stenbakken, (301) 975-2440]

Other Fast Signal Topics

Recently Published

Oates, C.W., and Young, M., **Microscope Objectives, Cover Slips, and Spherical Aberration**, Applied Optics, Vol. 26, No. 11, p. 2043 (June 1, 1987).

Microscope objectives with powers of 20X and higher will display significant spherical aberration when used to examine an optical fiber without a cover slip.
[Contact: Matt Young, (303) 497-3223 or -5342]

ELECTRICAL SYSTEMS

Power Systems Metrology

Released for Publication

Anderson, W.E., **A Calibration Service for Voltage Transformers and High-Voltage Capacitors**, to be published as a NBS Technical Note.

The National Bureau of Standards calibration service for voltage transformers and high-voltage capacitors is described. The service for voltage transformers supports the measurement of ratio correction factors and phase angles at primary voltages up to 170 kV and secondary voltages as low as 10 V at 60 Hz. Calibrations at frequencies from 50 to 400 Hz are available over a more limited voltage range. The service

Power Systems Metrology (cont'd.)

for high-voltage capacitors supports the measurement of capacitances and dissipation factors at applied voltages ranging from 100 V to 170 kV at 60 Hz depending on the nominal capacitance. Calibrations over a reduced voltage range at other frequencies are also available. As in the case with voltage transformers, these voltage constraints are determined by the facilities at the National Bureau of Standards.
[Contact: William E. Anderson, (301) 975-2423]

Kelley, E.F., Nehmadi, M., Hebner, R.E., McKenny, P.J., and Forster, E.O., **Simultaneous Measurement of Light Emission, Current Pulses and Growth of Prebreakdown Streamers in Hexane**, to be published in the Proceedings of the 1987 Conference on Electrical Insulation and Dielectric Phenomena, Gaithersburg, Maryland, October 19-22, 1987.

High-speed, image-converter photography is used to document the growth characteristics of prebreakdown phenomena emanating from a cathode needle in a needle-sphere electrode system placed in a liquid. The cathode streamer growth characteristics are compared to the pulsed nature of the current feeding the streamer and light emission from the streamer. The fact that there is a strong temporal correlation between the current and light pulses is confirmed. However, it is found that no strong correlation exists between this pulse-like behavior and the growth of the prebreakdown event, but that the streamer is found to grow rather uniformly despite the discreet nature of the current supplied. This information should contribute to the development of theoretical modeling efforts on the generation and development of prebreakdown phenomena in liquids.
[Contact: Edward F. Kelley, (301) 975-2424]

Misakian, M., and Anderson, W.E., **The NBS Electric Fields Project: 1987 Update.**

The objectives of the NBS Electric Fields Project include the evaluation of instrumentation and measurement techniques which are used to characterize the electrical parameters in the vicinity of high-voltage transmission lines and in laboratory apparatus designed to simulate the transmission line environment. During the past year, work has continued on developing instrumentation for measuring the mobility distribution of atmospheric ions produced by corona in air. The mobility K of an ion as it moves through a gas under the influence of a weak electric field is defined as the average ion drift velocity divided by the electric field strength. Measurement of this ion parameter provides useful information regarding ion-molecule reactions in such areas as gaseous electronics and plasma chromatography. Knowledge of the ion mobility, in the high-voltage dc transmission line context, permits an experimental determination of charge density, ρ, using the relation $J=\rho KE$, where J and E are measured values of the ion current density and electric field strength, respectively. In addition, an estimate of the ion mass may be possible under certain conditions. The latter application would be useful for characterizing exposure conditions during bioeffects studies with dc electric fields and ions. While a complete characterization of the electrical environment in an exposure system would include identification of the ions, existing measurement systems require considerable expertise and are not normally available for routine use. The simpler mobility measurement, while not as informative, could indicate changes in ion composition.

At last year's review, preliminary measurements of ion mobilities made using ac time of flight techniques and a prototype parallel plate drift tube were described. Since then two cylindrical drift tubes employing guard rings have been fabricated and are being tested;

Power Systems (cont'd.)

one drift tube functions as an ac time-of-flight device and the other as a pulsed time-of-flight device. A description of the instrumentation and examples of time-of-flight spectra for ions produced by corona in air are presented. The mobility spectra obtained in untreated room air show considerable structure and week-to-week variation which suggests the need for some control of air composition in exposure systems during biological investigations. Data have also been obtained which show that double-mesh electrical shutters can act as mobility filters and thus affect the relative numbers of ions of different mobility observed in a time-of-flight spectrum. Other sources of measurement error using the two measurement approaches are described. The drift tubes differ in design from those normally employing guard rings. Instead of generating a nearly uniform drift electric field region with metal guard rings stacked in a vertical configuration with insulating spacers, the guard rings consist of coated conductive rings on the inside wall of a cylindrical insulating tube. Efforts to fabricate a drift tube with a uniform resistive coating on the inside wall of a cylindrical tube have been, to date, unsuccessful. The NBS Electric Fields Project is supported by the Office of Energy Storage and Distribution of the Department of Energy.
[Contact: Martin Misakian, (301) 975-2426]

Aschwanden, T., Van Brunt, R.J., and Bieber, M.E., **Analysis of Dielectric Strength Data for Binary Electronegative Gas Mixtures**, Proceedings of the XVIII International Conference on Phenomena in Ionized Gases, University of Wales, Swansea, United Kingdom, July 12-16, 1987, pp. 102-103.

The consistency among dielectric strength, electron swarm, and collision cross-section data for ionization, attachment, and momentum transfer have been determined for the binary gas mixtures SF_6/He, SF_6/Ne, SF_6/Ar, and SF_6/CO_2 using a theoretical approach recently developed by Van Brunt. Dielectric strength data for SF_6/Ar and SF_6/CO_2 measured by Aschwanden can be accurately described by the model calculation and exhibit a high degree of consistency with swarm and cross-section data. The model also appears to successfully describe preliminary electrical breakdown data for SF_6/Ne mixtures. The theoretical model fails for SF_6/He because it does not allow for the important effect of Penning ionization which is possible in this case.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Fitzpatrick, G.J., Forster, E.O., Hebner, Jr., R.E., and Kelley, E.F., **Prebreakdown Cathode Processes in Liquid Hydrocarbons**, IEEE Transactions on Electrical Insulation, Vol. EI-22, No. 4, pp. 453-458 (August 1987).

Measurements are presented of the initiation of prebreakdown streamers at a point cathode in liquid hydrocarbons. Using a computer implementation of the method of images, the electric field is computed for selected geometries to confirm that the field strengths in the vicinity of these streamers are probably high enough so that electron multiplication processes can occur. High-magnification photographs of streamer initiation show that the initial streamer velocity is $(2.8 \pm 0.4) \times 10^4$ cm/s in toluene.
[Contact: Robert E. Hebner, Jr., (301) 975-2403]

Hebner, Jr., R.E., **Research for Electric Energy Systems - An Annual Report**, NBSIR 87-3643 (September 1987).

This report documents the technical progress in the five investigations which make up the project "Support of Research Projects for Electrical Energy Systems," funded by the U.S. Department

Power Systems (cont'd.)

of Energy. To support the measurement of ions in the dc transmission line environment, techniques to measure ion mobility were evaluated. In addition, techniques were developed to determine the sensitivity of an AM radio to detect partial discharges in a biological exposure facility. Within the project to develop measurement techniques and obtain basic data for gaseous dielectrics, a theoretical method was developed to evaluate the consistency among electron collision, transport, and dielectric strength data for binary gas mixtures; the gas phase hydrolysis rates for SOF_2 and SOF_4 were measured; the corona discharge oxidation mechanisms were identified and the role of negative ions on the SOF_4 yield was determined. Progress in interfacial measurements included the optical measurement of the electric field distribution as a streamer initiates. Progress in developing measurements for nanosecond dielectrics was in the characterization of the errors in the measurement of voltage pulses using E-dot probes and the identification of the reducation of breakdown voltage in oil for faster pulses.
[Contact: Ronald H. McKnight, (301) 975-2403]

Hebner, R.E., Kelley, E.F., FitzPatrick, G.J., and Forster, E.O., **The Effect of Pressure on Streamer Inception and Propagation in Liquid Hydrocarbons**, Proceedings of the Ninth International Conference on Conduction and Breakdown in Dielectric Liquids, Salford, United Kingdom, July 27-31, 1987, unpaged (July 1987).

This paper shows that for pressures between 0.1 and 5.0 MPa, the structure of a streamer originating from a cathode is significantly modified while that initiating from an anode is relatively unchanged, in toluene and hexane. For cathode streamers, the inception voltage increased from 40 ± 6 kV at 0.1 MPa to 99 ± 22 kV at 5.0 MPa. For anode streamers, the inception voltage increased from 53 ± 6 kV at 0.1 MPa to 123 ± 55 kV at 5.0 MPa.
[Contact: Edward F. Kelley, (301) 975-2424]

Hillhouse, D.L., **Assessment of Future Optical Measurements of Voltage and Current in Electric Power Systems**, Optical Power Line Voltage and Current Measurement Systems; Electric Power Research Institute Report EPRI EL-5431, Vol. 2 (September 1987).

This report summarizes the results of an investigation into the technical and economic justifications for improving power system voltage and current measurements, with special emphasis on the prospects for doing this using optical technology. The investigation consisted of gathering, analyzing, and summarizing information obtained specialists in over a dozen representative major utilities, and from nearly twenty equipment manufacturers. From this and other information, an assessment of measurement needs and of the availability of the requisite technology was developed.

The report concludes that although the technical and economic arguments either for or against optical technology for power system measurements are inconclusive, there is a widespread consensus that optical technology will become incorporated into the power grid. The consensus is based on such factors as the need for more accurate metering and the increasing automation of the power grid.
[Contact: Ronald H. McKnight, (301) 975-2403]

Oldham, N.M., Laug, O.B., and Waltrip, B.C., **Digitally-Synthesized Power Calibration Source**, IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 341-346 (June 1987) [CPEM 86 Proceedings issue].

A digitally synthesized source of "phantom" power for calibrating electrical power and energy meters is described. Independent sources of voltage, current,

Power Systems (cont'd.)

and phase angle are programmable between 0 and 240 V, 0 and 5 A, and 0 and 360 deg, respectively. The accuracy of the active and reactive power is estimated to be within ±100 ppm of the full scale apparent power (volt-amperes).
[Contact: N. Michael Oldham, (301) 975-2408]

Petersons, O., and Mehta, S.P., **An Active High Voltage Divider and Phase Shifter,** IEEE Transactions on Instrumentation and Measurement, Vol. IM-36, No. 2, pp. 362-368 (June 1987) [CPEM 86 Proceedings issue].

An instrument combining the functions of an active high voltage divider and a phase shifter designed to yield small phase-angle uncertainties within 20 μrad is described. It is based on a circuit employing a feedback amplifier and a controlled source. The presence of the controlled source greatly reduces the potential of dynamic instabilities of the feedback loop and effectively eliminates the errors associated with the finite gain of the amplifier. Design and construction details and the results of the accuracy evaluation are presented.
[Contact: Oskars Petersons, (301) 975-2400]

Sieck, L.W., and Van Brunt, R.J., **Transfer of F^- in Collisions of SF_6^- with Fluorinated Gases and SO_2 at Thermal Energies,** Proceedings of the Fifteenth International Conference on the Physics of Electronic and Atomic Collisions, Brighton, United Kingdom, July 22-28, 1987, p. 710.

Measured temperature dependences of F^- transfer rates for collisions of SF_6^- with SOF_2, SO_2F_2, SOF_4, SO_2, SF_4, and SiF_4 are reported. The results are used to interpret the complex anionic chemistry that occurs during electrical discharges in SF_6.
[Contact: Richard J. Van Brunt, (301) 975-2425]

Superconductors

Released for Publication

Chen, D.-X., Goldfarb, R.B., Nogues, J., and Rao, K.V., **Susceptibility Measurements of a Sintered and Powdered Y-Ba-Cu-O Superconductor.**

The real and imaginary parts of magnetic ac susceptibility of a sintered Y-Ba-Cu-O superconductor were measured as functions of temperature. The susceptibility may be separated into two contributions, one sensitive and the other relatively insensitive to the magnitude of the measuring field. The former is partially suppressed upon coarsely crushing the sample. It is completely suppressed after finely powdering, whereupon the susceptibility curves become insensitive to the magnitude of the measuring field. Several models might be consistent with the results.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Ekin, J.W., Capone, D.W., Zaluzec, N., Flandermeyer, B., deLima, O.F., Braginski, A.I., Panson, A.J., Janocko, M.A., Hong, M., Kwo, J., and Liou, S.H., **Evidence for Anisotropy Limitation on the Transport Critical-Current in Polycrystalline $Y_1Ba_2Cu_3O_x$.**

Measurements of the transport critical-current (J_c), magnetization J_c, and magnetoresistance in a number of bulk sintered samples of $Y_1Ba_2Cu_3O_x$ from several different laboratories are dominated by "weak-link" regions between high-J_c regions. The weak-link J_c has a tunneling character, decreasing by two orders of magnitude as the magnetic field is increased from 0.1 mT to 10 mT, at 77 K. An examination of the grain boundary region in $Y_1Ba_2Cu_3O_x$ shows no impurities or nonstoichiometric regions on a scale of 5 A. These microscopy data and recent reports of intrinsic anisotropy of J_c in single crystals are consistent with a significant part of the weak-link phenomena in polycrys-

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talline bulk $Y_1Ba_2Cu_3O_x$ being caused by grains oriented with their weak-conduction axis in the direction of current flow. Orienting the grains in the powder state during processing may result in high J_c in bulk $Y_1Ba_2Cu_3O_x$.
[Contact: John W. Ekin, (303) 497-5448]

Kamper, R.A., and Clark, A.F., **Superconductivity: Challenge for the Future**, to be published in the Proceedings of the Federal Conference on Commercial Applications of Superconductivity, Washington, DC, July 28-29, 1987.

This is a brief report on the Federal Conference on Commercial Applications of Superconductivity, Washington, DC, July 28-29, 1987.
[Contact: Robert A. Kamper, (303) 497-3535]

Moreland, J.M., Goodrich, L.F., Ekin, J.W., Capobianco, T.E., and Clark, A.F., **Anomalous Behavior of Tunneling Contacts in Superconducting Perovskite Structures**, to be published in Advances in Cryogenic Engineering (Materials), Vol. 34.

Our break junction results for electron tunneling spectroscopy of the perovskite superconductors La-Sr-Cu-O and Y-Ba-Cu-O are similar to those obtained using thin-film, scanning tunneling microscopy, and point-contact methods. Energy gap structures are sometimes observed in the measured current-voltage characteristics. More often, however, the characteristics are anomalous when compared to previous tunneling studies of BCS superconductors. The anomalies include linearly increasing conductance with voltage, large deviations in junction conductance above the gap edge, and junction diode action. We discuss some possible explanations for these observations.
[Contact: John M. Moreland, (303) 497-3641]

Recently Published

Goldfarb, R.B., Clark, A.F., Braginski, A.I., and Panson, A.J., **Evidence for Two Superconducting Components in Oxygen-Annealed Single-Phase Y-Ba-Cu-O**, Cryogenics, Vol. 27, pp. 475-480 (September 1987).

The complex susceptibility of a sintered Y-Ba-Cu-O superconductor is strongly dependent on ac field amplitude, H. Very small values of H must be used for the real part of susceptibility, χ', to reach a value corresponding to bulk diamagnetism just below the critical temperature, T_c. The imaginary part, χ'', represents hysteresis loss in the sample. Thus, χ'' versus temperature becomes positive when H exceeds the lower critical field, H_{c1}, of the superconductor.

Annealing the material in oxygen gives rise to two distinct components, a relatively high-T_c, high-H_{c1} superconductor (denoted as 'G' or 'good') and a relatively low-T_c, low-H_{c1} superconductor (denoted as 'B' or 'bad'). Curves of susceptibility versus increasing temperature reflect the dual nature of the annealed sample: χ' has an inflection at the T_c of the B component and approaches zero at the T_c of the G component, while χ'' has a peak at each T_c. Both critical temperatures decrease linearly with increasing H, though at very different rates. H_{c1} of the G component is considerably greater than H_{c1} of the B component. The lower critical fields are linearly decreasing functions of temperature.

Two models might explain the susceptibility data. In the grain model, the G component consists of superconducting grains, and the B component is either intergranular material, unfavourably orientated anisotropic grains, or oxygen-depleted grain boundaries. In the surface model, the G component is in the interior of the sample, and the B com-

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ponent is at the sample's surface. This condition could arise if there was oxygen depletion at the surface subsequent to total enrichment during annealing.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Goldfarb, R.B., Clark, A.F., Panson, A.J., and Braginski, A.I., **AC Susceptibility Measurements Near the Critical Temperature of a Y-Ba-Cu-O Superconductor**, Proceedings of Symposium S, 1987 Materials Research Society Meeting, Anaheim, California, April 23-24, 1987, pp. 261-263.

The loss component of complex susceptibility of a Y-Ba-Cu-O superconductor near its critical temperature is strongly dependent on ac field amplitude but virtually independent of frequency. This implies that magnetic hysteresis is the major loss mechanism in these materials. The temperature at which the loss first becomes positive upon warming corresponds to an equivalence between the amplitude of the ac field and the lower critical field of the superconductor.
[Contact: Ronald B. Goldfarb, (303) 497-3650]

Moreland, J.M., **Squeezable Junctions for Electron Tunneling and Surface Electric Field Experiment**, The Physics Teacher, pp. 405-411 (October 1986).

Mechanically adjusted junctions can be used for electron tunneling or surface electric field measurements. This article conceptualized their application to semiconductors, superconductors, and surface physics of conducting materials.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Clark, A.F., Ku, H.C., and Shelton, R.N., **Electron Tunneling Measurement of the Energy Gap in a La-Sr-Cu-O Superconductor**, Cryogenics, Vol. 27, pp. 227-228 (May 1987).

We have used the break-junction technique to determine the energy gap of lanthanum-strontium-copper-oxide, one of the new high-critical-temperature superconductors. The current-voltage characteristics demonstrated a variety of tunneling behaviours. The best characteristic indicating quasiparticle tunneling between superconducting electrodes implied an energy gap of 7.0 ± 0.1 meV. Derivatives of other characteristics showed weak structure indicating possible energy gaps up to 9 meV.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Ekin, J.W., Goodrich, L.F., Capobianco, T.E., Clark, A.F., Kwo, J., Hong, M., and Liou, S.H., **Break-Junction Tunneling Measurements of the High-T_c Superconductor $Y_1Ba_2Cu_3O_{9-\delta}$**, Physical Review B, Vol. 35, No. 16, pp. 8856-8857 (June 1, 1987).

Current-voltage tunneling characteristics in a high-critical-temperature superconducting material containing predominately $Y_1Ba_2Cu_3O_{9-\delta}$ have been measured using the break-junction technique. Sharp gap structure was observed, with the largest superconductive energy gap measured to be $\Delta = 19.5 \pm 1$ meV, assuming a superconductor-insulator-superconductor junction. This energy gap corresponds to $2\Delta/k_BT_c = 4.8$ at $T = 4$ K, for a critical temperature of 93 K (midpoint of the resistive transition).
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Clark, A.F., Goodrich, L.F., Ku, H.C., and Shelton, R.N., **Tunneling Spectroscopy of a La-Sr-Cu-O Break Junction: Evidence for Strong-Coupling Superconductivity**, Physical Review B, Vol. 35, No. 16, pp. 8711-8713 (June 1, 1987).

Detailed structure in the quasiparticle tunneling has been observed in La-Sr-Cu-O superconductive tunneling junctions using the break-junction tech-

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nique. Variability in the energy gap and associated structure in the current-voltage curves are observed indicating significant inhomogeneity in the superconducting properties. Large energy gaps (7.0 meV) and deep structure in the conductance derivative are evidence for a strong-coupling mechanism.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Goodrich, L.F., Ekin, J.W., Capobianco, T.E., and Clark, A.F., **Electron Tunneling Measurements of High T_c Compounds Using Break Junctions**, Japanese Journal of Applied Physics, Vol. 26, Supplement, No. 26-3, pp. 999-1000 (August 1987). [Proceedings of the 18th International Conference on Low Temperature Physics, Kyoto, Japan, August 10-16, 1987.]

We report on the break junction technique and its application to the high T_c superconductors LaSrCuO and YBaCuO. In this technique, bulk samples are fractured and the freshly fractured surfaces adjusted to form a tunneling junction with vacuum or liquid helium as the insulating barrier. Precise mechanical adjustment permits the study of electron tunneling phenomena between pieces of a bulk superconductor. The current-voltage characteristics of these break junctions are variable, indicating sample inhomogeneity. However, some junction settings result in the more familiar quasi-particle signatures in the current-voltage characteristics. Low-leakage junctions indicate the presence of a sharp superconductive energy gap as well as large variations in junction conductance above the gap edge in both materials.
[Contact: John M. Moreland, (303) 497-3641]

Moreland, J.M., Goodrich, L.F., Ekin, J.W., Capobianco, T.E., Clark, A.F., Braginski, A.I., and Panson, A.J., **Josephson Effect Above 77 K in a YBaCuO Break Junction**, Applied Physics Letters, Vol. 51, No. 7, pp. 540-541 (August 17, 1987).

We have observed the Josephson effect in a YBaCuO break junction. Critical currents as high as 10 mA were measured at 4 K for break junctions with a point contact within the fracture of a sample. The junction was susceptible to microwave radiation showing Shapiro steps with the ratio of V/f of 2.04 ± 0.05 μV/Ghz compared to the pair tunneling value of h/2e = 2.068 μV/GHz. These steps were clearly visible in the current-voltage characteristics at temperatures up to 85 K.
[Contact: John M. Moreland, (303) 497-3641]

Magnetic Materials & Measurements

Released for Publication

Capobianco, T.E. and Vecchia, D.F., **Coil Parameter Influence on Eddy Current Probe Sensitivity**, to be published in the Proceedings of the Review of Progress in Quantitative Non-Destructive Evaluation.

Results of a study undertaken to quantify causes of sensitivity variations found in commercial eddy current probes are reported. Electrical parameter measurements made on a number of commercially produced coils indicate that coil reproducibility is not a major problem in the probe construction process. On the other hand, commercial probes designed for a particular inspection can have sensitivities differing by almost an order of magnitude. It appears that while individual probe manufacturers can produce many identical probes, the choice of coil design parameters can lead to flaw-detectability variations in eddy current probes obtained from different sources.

This study evaluates the effects on sensitivity of changes in the physical parameters of small ferrite core coils. Among the parameters studied were wire gauge, number of wire turns, coil aspect

Magnetic Materials, etc. (cont'd.)

ratio, ferrite permeability, and operating frequency. The criteria used to gauge probe sensitivity are the impedance changes observed on applying the coils to four semi-elliptical electrical-discharge-machined notches in aluminum and to aluminum and titanium test blocks. The results indicate that coils with similar electrical characteristics but different physical parameters can have significant differences in sensitivity.
[Contact: Thomas E. Capobianco, (303) 497-3141]

Recently Published

Capobianco, T.E., **A Review of Eddy Current Research at the National Bureau of Standards in Boulder, Colorado,** Proceedings of the DoD Conference on Nondestructive Evaluation, Charleston, South Carolina, October 29-31, 1985, pp. 164-173 (August 1987).

On-going research in eddy current nondestructive evaluation at the National Bureau of Standards in Boulder, Colorado, is reviewed. The most recent results and publications of experimental and theoretical studies are presented. This includes the areas of eddy current coil characterization and field mapping, experimental verification of eddy current-fatigue crack interaction, uniform field probe calibration, artifact standards, fatigue crack growth monitoring, and differential eddy current probe studies.
[Contact: Thomas E. Capobianco, (303) 497-3141]

Capobianco, T.E., and Fickett, F.R., **A Proposed Military Standard for Commercial Eddy Current Probes Based on Performance Characterization,** Proceedings of the 35th Defense Conference on Nondestructive Testing, Hill Air Force Base, Utah, October 28-30, 1986, pp. 135-141 (October 1986).

The latest results of the work being done on a draft military standard for characterizing commercial eddy current probes are reported. We discuss measurement techniques that have been evaluated for suitability as a characterization test method, such as field mapping and various electrical parameter measurements, and the reasons for selecting the method which has been incorporated in the present draft. Our conclusion is that the measurement of impedance change of a probe over a range of frequencies on two metals of different conductivities offers the best indicator of eddy current probe sensitivity and proper operating range.
[Contact: Thomas E. Capobianco, (303) 497-3141]

ELECTROMAGNETIC INTERFERENCE

Radiated Electromagnetic Interference

Released for Publication

FitzGerrell, R.G., and Treado, M.J., **Monopole Impedance and Gain Measurements of Finite Ground Planes,** to be published as National Institute of Justice Report 200-87.

The purpose of the work described in this report is to determine if it is possible to make acceptably accurate input impedance and gain measurements of monopoles on a reduced size ground plane. Ideally, monopoles are measured with the antenna located on an infinite, perfectly conducting, ground plane. Practically, measurements are usually made on a test site with a highly conducting ground plane whose radius is at least 2λ, where λ is the wavelength. At 25 MHz, the lowest frequency considered in this report, such a ground plane would require a space at least 48 m (157 ft.) in diameter. Model impedance measurements and calculations presented in this report imply that a space on the order of 10 by 11 m (33 by 36 ft.) may be sufficient if the researcher uses 16 resistively loaded wire radials to extend a 3.66 by 4.88 m (12 by 16 ft.) solid metal ground plane. Measured and

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solid metal ground plane. Measured and calculated monopole SWR and insertion loss on a full-scale ground plane verify the results of the model measurements.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Koepke, G.H., Hill, D.A., and Ma, M.T. **Analysis of an Array of Log-Periodic Dipole Antennas for Generating Test Fields**, to be published as NBSIR 87-3068.

An analysis of log-periodic dipole antennas was extended to study their use in arrays designed for electromagnetic susceptibility measurements. Parameters ot an array of five log-periodic dipole antennas were calculated and in some cases compared to a single log-periodic dipole antenna. These parameters were used to evaluate the tradeoffs that exist in the design of an optimum transmitting antenna for susceptibility measurements.
[Contact: Galen H. Koepke, (303) 497-5766]

Ma, M.T., **Understanding Reverberating Chambers as an Alternative Facility for EMC Testing.**

A relatively new facility called a reverberating chamber designed for electromagnetic compatibility (EMC) testing is described. The purpose is to create a statistically uniform electric field inside a metal enclosure for testing radiated susceptibility or immunity of equipment. Design criteria in terms of the number of cavity modes, mode density, and composite quality factor are presented in detail in order to understand the physical insight and to enhance interpretations of measurement results. Recent experimental data are included to illustrate the underlying principle.
[Contact: Mark T. Ma, (303) 497-3800]

Wu, D.I., and Chang, D.C., **An Investigation of a Ray-Mode Representation of the Green's Function in a Rectangular Cavity**, to be published as NBS Technical Note 1312.

In a rectangular cavity, it is well known that a point source-excited field can be represented either in terms of summation of modes or in terms of rays produced by the equivalent image sources. Both representations involve series that are slowly convergent, so computation of fields inside the cavity is difficult. To obtain a numerically efficient scheme, a hybrid ray-mode representation is developed here using the finite Poisson summation formula. The modal representation is modified in such a way that all the modes near resonance are retained while the truncated remainder of the mode series is expressed in terms of a weighted contribution of rays. For a large cavity, the contribution of rays from far away images becomes small, therefore the ray sum can be approximated by one or two dominant terms without a loss of numerical accuracy. To illustrate the accuracy and the computational simplification of this ray-mode representation, numerical examples are included with the conventional mode series (summed at the expense of long computation time) serving as a reference.
[Contact: Doris I. Wu, (303) 497-3214]

Recently Published

Camell, D.G., Larson, E.B., and Cruz, J.E., **NBS Calibration Procedures for Horizontal Dipole Antennas (25 to 1000 MHz)**, NBS Technical Note 1309 (April 1987).

This publication describes the theoretical basis and test procedures for horizontally polarized dipole calibrations at the National Bureau of Standards. Two different techniques and two different test sites are used. The standard antenna method uses the calculation of a field strength level, from the response of a simple half-wave dipole, to calibrate an antenna. This method is used at an open field site in

Radiated EMI (cont'd.)

of 200 MHz to 1000 MHz. Procedures for both techniques are explained and measurement setups are illustrated. Measurement uncertainties are discussed. Sample reports are included for both methods.
[Contact: Dennis G. Camell, (303) 497-3214]

FitzGerrell, R.G., **Standard Linear Antennas, 30 MHz to 1000 MHz**, IEEE Transactions on Antennas and Propagation, Vol. AP-34, No. 12, pp. 1425-1429 (December 1986). [Proceedings of the Conference on Electromagnetic Compatibility, University of York, United Kingdom, September 28-October 2, 1986, pp. 147-153].

It is demonstrated that the insertion loss between pairs of thin, linear antennas may be calculated using fairly simple equations that are generally considered to be good engineering approximations. Although the insertion loss calculation does not involve antenna gain directly (some measurements are actually made in the near-field where gain is not defined), the result is precisely the quantity obtained using the antenna gains in Friis's transmission formula, assuming the mismatch loses are zero. Therefore, the antenna gain product is implicit in the more general insertion loss equations. The particular measurement of insertion loss used here yields a quantity called site attenuation by electromagnetic compatibility engineers. A close agreement between measured and calculated data provides confidence in the site attenuation calculations when the site is essentially perfect, and provides confidence in the gain product of the antenna pair calculated using basically the same equations as those used for insertion loss. It is assumed that one-half of the mean value of the difference between the calculated and measured data is a good estimate of individual antenna performance. For the antennas described here, this measure of performance is typically ≤ 0.05 dB and on the outside, ≤ 0.42 dB.
[Contact: Richard G. FitzGerrell, (303) 497-3737]

Hill, D.A., **Effect of a Thin Conducting Sheet on the Fields of a Buried Magnetic Dipole**, Electromagnetics, Volume 7, pp. 71-79 (1987).

The effect of a thin conducting sheet on the fields of a subsurface vertical magnetic dipole has been analyzed. The integral representation of the fields has been evaluated numerically, and numerical results for the vertical magnetic field above the source at the surface are presented in parametric form. It is found that the predicted fields give better agreement with previous transmission measurements than do the fields of a homogeneous half-space model.
[Contact: David A. Hill, (303) 497-3472]

Conducted Electromagnetic Interference

Released for Publication

Kanda, M., **A Microstrip Patch Antenna as a Standard Transmitting and Receiving Antenna.**

This paper discusses the possibility of employing a microstrip patch antenna as a standard transmitting antenna. The intrinsic properties of the substrate used for the antenna are determined by careful impedance measurements. The experimental results indicate that the transmitting characteristics of a microstrip antenna can be theoretically determined from its geometry. The microstrip patch antenna discussed here is physically small (20 cm^2 for 450 MHz) and can be well matched to a power delivery system (SWR = 1.17).
[Contact: Motohisa Kanda, (303) 497-5320]

Recently Published

Bell, B.A., **A Report on the NBS/CEEE**

Conducted EMI (cont'd.)

Survey of Electronic Measurement Needs Below 10 MHz, Proceedings of the National Conference of Standards Laboratories, 1987 Workshop and Symposium, Denver, Colorado, July 12-16, 1987, pp. 75-1 - 75-14.

This paper describes the results of a recent survey conducted by the Electrosystems Division of the Center for Electronics and Electrical Engineering (CEEE) at the National Bureau of Standards (NBS). A summary analysis is provided of the data obtained on questions concerning (1) critical electrical quantities and associated instrumentation and devices, (2) automatic test equipment (ATE)/complex measurement systems, and (3) conducted electromagnetic interference.
[Contact: Barry A. Bell, (301) 975-2402]

Martzloff, F.D., and Wilson, P.F., **Fast Transient Tests - Trivial or Terminal Pursuit?**, Proceedings of the Electromagnetic Compatibility 1987, Zurich, Switzerland, March 3-5, 1987, pp. 283-288 (March 1987).

Measurements, augmented by theoretical simulation techniques, have been performed to determine the attenuation of fast transients propagating in typical indoor (conduit-enclosed) power lines. The rise time of the applied pulses ranges from 0.7 to 50 ns, including the International Electrotechnical Commission (IEC) 5/50 ns pulse recently recommended for fast transient tests. Theory and measurements confirm that pulse amplitude attenuation increases significantly for shorter pulses. For comparison and validation of the theoretical model, the IEC pulse was also applied to a conventional coaxial cable.
[Contact: Francois D. Martzloff, (301) 975-2409]

ADDITIONAL INFORMATION

Lists of Publications

Gibson, K.A., Page, J.M., and Miller, C.K.S., **A Bibliography of the NBS Electromagnetic Fields Division Publications,** NBSIR 85-3040 (February 1986).

This bibliography lists publications of the National Bureau of Standards' Electromagnetic Fields Division for the period from January 1984 through September 1985, with selected earlier publications from the Division's predecessor organizations.
[Contact: Kathryn A. Gibson, (303) 497-3132]

Kline, K.E., and DeWeese, M.E., **Metrology for Electromagnetic Technology: A Bibliography of NBS Publications,** NBSIR 87-3074 (June 1987).

This bibliography lists the publications of the personnel of the Electromagnetic Technology Division of NBS in the period from January 1970 through December 1986. A few earlier references that are directly related to the present work of the Division are included.
[Contact: Kathryn E. Kline, (303) 497-3678]

Palla, J.C., and Meiselman, B., **Electrical and Electronic Metrology: A Bibliography of NBS Electrosystems Division Publications, NBS List of Publications 94** (January 1988).

This bibliography covers publications of the Electrosystems Division, Center for Electronics and Electrical Engineering, NBS, and of its predecessor sections for the period January 1963 to January 1988. A brief description of the Division's technical program is given in the introduction.
[Contact: Jenny C. Palla, (301) 975-2220]

Walters, E.J., **Semiconductor Measurement Technology, NBS List of Publications 72,** [a bibliography of NBS publications for the years 1962-1987] (March 1988).

This bibliography contains reports of

Lists of Publications (cont'd.)

work performed at the National Bureau of Standards in the field of Semiconductor Measurement Technology in the period from 1962 through December 1987. An index by topic area and a list of authors are provided. [Contact: E. Jane Walters, (301) 975-2050]

1988 CEEE Calendar

February 10-12 (San Diego, CA)

IEEE Semiconductor Thermal and Temperature Measurement Symposium. This fourth annual **SEMI-THERM** symposium is sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE in cooperation with NBS and constitutes an international forum for the presentation of new developments in, and applications relating to, generation and removal of heat within semiconductor devices and measurement of junction temperatures experienced in various applications and environments. Major SEMI-THERM topic areas include thermal measurements, thermal characterization, applications, and computation and software.

The program includes keynote speakers, technical presentations, tutorial sessions, workshops, and an exhibit. In addition, the Semiconductor Equipment and Materials Institute has scheduled in conjunction with SEMI-THERM a meeting of its Thermal Measurements Task Force, to which attendees are invited. [Contact: Frank F. Oettinger, (301) 975-2054]

May 11-13 (Los Angeles, CA)

Intersociety Conference on Thermal Phenomena in Fabrication and Operation of Electronic Components. This Conference is sponsored by the Components, Hybrids, and Manufacturing Technology Society of the IEEE, in cooperation with ASME Committee K-16 on Heat Transfer and NBS. It is intended to provide an interdisciplinary forum for exploring the progress made in understanding, analyzing, and modeling thermal transport processes and thermally induced failures in the fabrication, assembly, and use of logic, memory, and data-storage systems. Major topic areas covered are 1) processing and fabrication, including state-of-the-art semiconductor crystal growing techniques; thermal stress in wafers, chips, substrates, PC boards, and joints; and encapsulant behavior with respect to solidification, outgassing, mechanical properties, and water vapor diffusion and absorption; 2) packaging technology, including means for cooling components from cryogenic to high temperatures and reliability as affected by failure mechanisms such as dopant migration and intermetallic growth; and 3) peripheral equipment, including data storage in both magnetic and optical media and thermal issues in dot-matrix and thermal printer heads. The conference is being held in conjunction with the Electronics Components Conference (May 9-11) at the same site. [Contact: Frank F. Oettinger, (301) 975-2054]

September 12-14, 1988 (San Jose, CA)

VLSI and GaAs Chip Packaging Workshop. This Workshop is co-sponsored by the Components, Hybrids, and Manufacturing Technology Society of IEEE and NBS; attendees are expected to be knowledgeable in the field and to participate in discussions. Topic areas include: VLSI and wafer-scale package design (characterization and implementation, cost and performance-driven solutions); package thermal design (characteristics, results, and issues); package interconnection options (wire bonding, TAB, flip chip, or optical); GaAs IC packaging (high-speed packaging considerations); package electrical issues (reduction of parasitics, improvements in electrical

1988 CEEE Calendar (cont'd.)

performance, reduction in line resistance); integrating package design (from die to system, including assembly and test issues); VLSI package materials advancements; die-attach solutions for large chips; and new failure mechanisms in VLSI packaging. [Contact: George G. Harman, (301) 975-2097]

Planned

Early summer (Vail, CO)

Combined Short Course on Optical Fiber and Laser Measurements. [Contact: Aaron A. Sanders, (303) 497-5341]

Early fall (Boulder, CO)

Fiber Optics Symposium. [Contact: Aaron A. Sanders, (303) 497-5341]

Late fall (Boulder, CO)

Symposium on Optical Materials for High Power Lasers (20th Boulder Damage Symposium). [Contact: Aaron A. Sanders, (303) 497-5341]

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All technical information included in this document has been approved for publication previously.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

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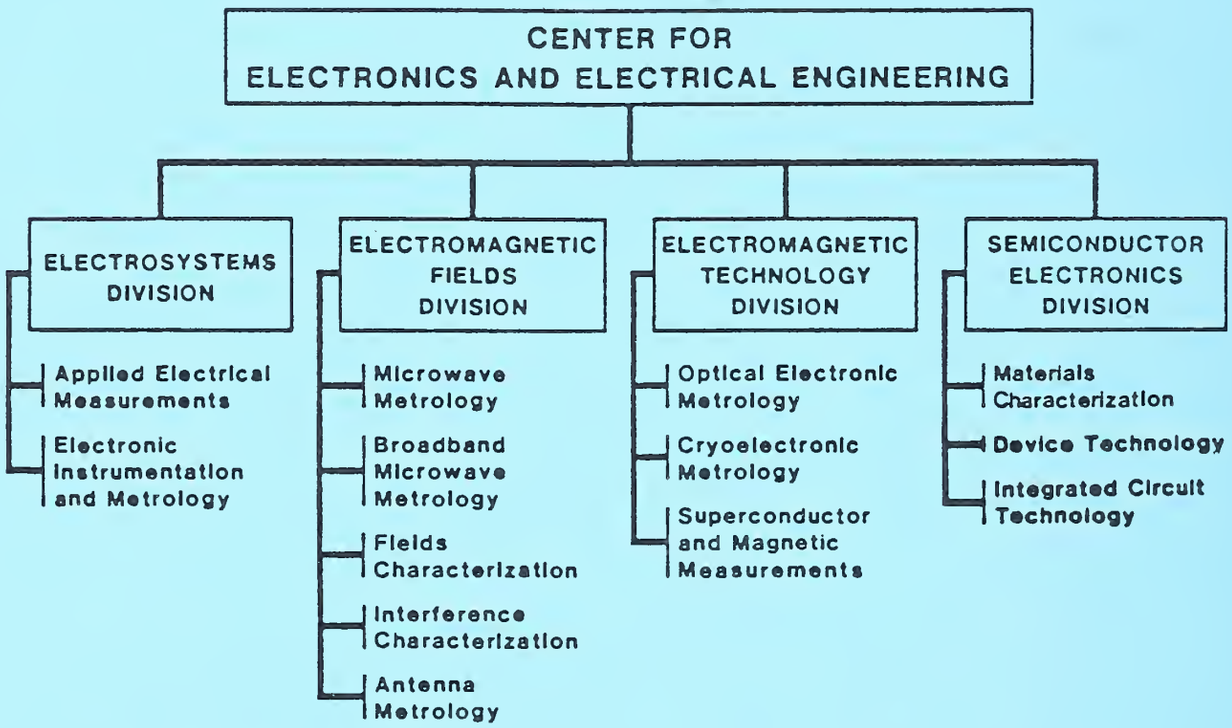

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